Chapter 1. Introduction

This chapter describes the purpose for the preparation of this fugitive dust handbook; presents a brief overview/primer on fugitive dust that includes a summary of factors affecting dust emissions, an overview of emission calculation procedures (including a discussion of emission factors), and a discussion of options for controlling emissions; and summarizes the organizational structure of the handbook.

1.1 Background

Most of the more than 70 areas of the United States that have been unable to attain the national ambient-air quality standards (NAAQS) for PM10 (particles smaller than 10 µm in aerodynamic diameter) are in western states with significant emission contributions from fugitive dust sources. Fugitive dust sources may be separated into two broad categories: process sources and open dust sources. Process sources of fugitive emissions are those associated with industrial operations such as rock crushing that alter the characteristics of a feed material. Open dust sources are those that generate non-ducted emissions of solid particles by the forces of wind or machinery acting on exposed material. Open dust sources include industrial sources of particulate emissions associated with the open transport, storage, and transfer of raw, intermediate, and waste aggregate materials, and nonindustrial sources such as unpaved roads and parking lots, paved streets and highways, heavy construction activities, and agricultural tilling.

On a nationwide basis, fugitive dust consists mostly of soil and other crustal materials. However, fugitive dust may also be emitted from powdered or aggregate materials that have been placed in open storage piles or deposited on the ground or roadway surfaces by spillage or vehicle trackout. Dust emissions from paved roadways contain tire and break wear particles in addition to resuspended road surface dust composed mostly of crustal geological material.

Generic categories of open dust sources include:

- Agricultural Tilling
- Construction and Demolition
    - Buildings
    - Roads
- Materials Handling
    - Batch drop (dumping)
    - Continuous drop (conveyor transfer, stacking)
    - Pushing (dozing, grading, scraping)
- Paved Travel Surfaces
    - Streets and highways
    - Parking lots and staging areas
- Unpaved Travel Surfaces
    - Roads
    - Parking lots and staging areas
- Wind Erosion of Exposed Areas
    - Agricultural Fields
    - Open Areas (vacant lots, desert land, unpaved surfaces)
    - Storage Piles

1.2 Purpose of the Handbook

In early 2004 the Western Regional Air Partnership's (WRAP) Dust Emissions Joint Forum (DEJF) selected the Countess Environmental project team composed of senior scientists/consultants from Countess Environmental and Midwest Research Institute to prepare a fugitive dust handbook and a website (www.wrapair.org/forums/dejf/fdh) for accessing the information contained in the handbook. The handbook and website are intended to:

- be used for technical and policy evaluations by WRAP members, stakeholders, and other interested parties when addressing specific air quality issues and when developing regional haze implementation plans;
- incorporate available information from both the public and private sectors that address options to reduce fugitive dust emissions in areas of the country classified as nonattainment for PM10; and
- serve as a comprehensive reference resource tool that will provide technical information on emission estimation methodologies and control measures for the following eight fugitive dust source categories: agricultural tilling, construction and demolition, materials handling, and travel on paved and unpaved roads as well as windblown dust emissions from agricultural fields, open areas of disturbed vacant land, and material storage piles.

The handbook and website will be updated as new information becomes available in the future. Additional fugitive dust source categories will be addressed in these future revisions.

1.3 Factors Affecting Dust Emissions

1.3.1 Mechanically Generated Dust

Mechanically generated emissions from open dust sources exhibit a high degree of variability from one site to another, and emissions at any one site tend to fluctuate widely. The site characteristics which cause these variations may be grouped into (a) properties of the exposed surface material from which the dust originates, and (b) measures of energy expended by machinery interacting with the surface. These site characteristics are discussed below.

Surface Material Texture and Moisture. The dry-particle size distribution of the exposed soil or surface material determines its susceptibility to mechanical entrainment. The upper size limit for particles that can become suspended has been estimated at ~ 75 µm in aerodynamic diameter.[1] Conveniently, 75 µm in physical diameter is also the smallest particle size for which size analysis by dry sieving is practical.[2] Particles passing a 200-mesh screen on dry sieving are termed "silt". Note that for fugitive dust particles, the physical diameter and aerodynamic diameter are roughly equivalent because of the offsetting effects of higher density and irregular shape. Dust emissions are known to be strongly dependent on the moisture level of the mechanically disturbed material.[1]

Water acts as a dust suppressant by forming cohesive moisture films among the discrete grains of surface material. In turn, the moisture level depends on the moisture added by natural precipitation, the moisture removed by evaporation, and moisture movement beneath the surface. The evaporation rate depends on the degree of air movement over the surface, material texture and mineralogy, and the degree of compaction or crusting. The moisture-holding capacity of the air is also important, and it correlates strongly with the surface temperature. Vehicle traffic intensifies the drying process primarily by increasing air movement over the surface.

Mechanical Equipment Characteristics. In addition to the material properties discussed above, it is clear that the physical and mechanical characteristics of materials handling and transport equipment also affect dust emission levels. For example, visual observation suggests (and field studies have confirmed) that vehicle emissions per unit of unpaved road length increase with increasing vehicle speed.[1] For traffic on unpaved roads, studies have also shown positive correlations between emissions and (a) vehicle weight and (b) number of wheels per vehicle.[3] Similarly, dust emissions from materials-handling operations have been found to increase with increasing wind speed and drop distance.

1.3.2 Wind Generated Dust

Wind-generated emissions from open dust sources also exhibit a high degree of variability from one site to another, and emissions at any one site tend to fluctuate widely. The site characteristics which cause these variations may be grouped into (a) properties of the exposed surface material from which the dust originates, and (b) measures of energy expended by wind interacting with the erodible surface. These site characteristics are discussed below.

Surface Material Texture and Moisture. As in the case of mechanical entrainment, the dry-particle size distribution of the exposed soil or surface material determines its susceptibility to wind erosion. Wind forces move soil particles by three transport modes: saltation, surface creep, and suspension. Saltation describes particles, ranging in diameter from about 75 to 500 µm, that are readily lifted from the surface and jump or bounce within a layer close to the air-surface interface. Particles transported by surface creep range in diameter from about 500 to 1,000 µm. These large particles move very close to the ground, propelled by wind stress and by the impact of small particles transported by saltation. Particles smaller than about 75 µm in diameter move by suspension and tend to follow air currents. As stated above, the upper size limit of silt particles (75 µm in physical diameter) is roughly the smallest particle size for which size analysis by dry sieving is practical. The threshold wind speed for the onset of saltation, which drives the wind erosion process, is also dependent on soil texture, with 100-150 µm particles having the lowest threshold speed. Saltation provides energy for the release of particles in the PM10 size range that typically are bound by surface forces to larger clusters. Dust emissions from wind erosion are known to be strongly dependent on the moisture level of the erodible material.[4] The mechanism of moisture mitigation is the same as that described above for mechanical entrainment.

Nonerodible Elements. Nonerodible elements, such as clumps of grass or stones (larger than about 1 cm in diameter) on the surface, consume part of the shear stress of the wind which otherwise would be transferred to erodible soil. Surfaces impregnated with a large density of nonerodible elements behave as having a "limited reservoir" of erodible particles, even if the material protected by nonerodible elements is itself highly erodible. Wind-generated emissions from such surfaces decay sharply with time, as the particle reservoir is depleted. Surfaces covered by unbroken grass are virtually nonerodible.

Crust Formation. Following the wetting of a soil or other surface material, fine particles will move to form a surface crust. The surface crust acts to hold in soil moisture and resist erosion. The degree of protection that is afforded by a soil crust to the underlying soil may be measured by the modulus of rupture (roughly a measure of the hardness of the crust) and thickness of the crust.[5] Exposed soil that lacks a surface crust (e.g., a disturbed soil or a very sandy soil) is much more susceptible to wind erosion.

Frequency of Mechanical Disturbance. Emissions generated by wind erosion are also dependent on the frequency of disturbance of the erodible surface. A disturbance is defined as an action which results in the exposure of fresh surface material. This would occur whenever a layer of aggregate material is either added to or removed from the surface. The disturbance of an exposed area may also result from the turning of surface material to a depth exceeding the size of the largest material present. Each time that a surface is disturbed, its erosion potential is increased by destroying the mitigative effects of crusts, vegetation, and friable nonerodible elements, and by exposing new surface fines.

Wind Speed. Under high wind conditions that trigger wind erosion by exceeding the threshold velocity, the wind speed profile near the erodible surface is found to follow a logarithmic distribution:[6]

$$u(z) = \frac{u*}{0.4} \ln \frac{z}{z_0} \quad (z > z_0) \tag{1}$$

where:

	u	=	wind speed (cm/s)
	$u*$	=	friction velocity (cm/s)
	z	=	height above test surface (cm)
	z_0	=	roughness height (cm)
	0.4	=	von Karman's constant (dimensionless)

The friction velocity *($u*$)* is a measure of wind shear stress on the erodible surface, as determined from the slope of the logarithmic velocity profile. The roughness height (z_0) is a measure of the roughness of the exposed surface as determined from the *y*-intercept of the velocity profile (i.e., the height at which the wind speed is zero) on a logarithmic-linear graph. Agricultural scientists have established that total soil loss by continuous wind erosion of highly erodible fields is dependent roughly on the cube of wind speed above the threshold velocity.[4] More recent work has shown that the loss of particles in suspension mode follows a similar dependence. Soils protected by nonerodible elements or crusts exhibit a weaker dependence of suspended particulate emissions on wind speed.[7]

Wind Gusts. Although mean atmospheric wind speeds may not be sufficient to initiate wind erosion from a particular "limited-reservoir" surface, wind gusts may quickly deplete a substantial portion of its erosion potential. In addition, because the erosion potential (mass of particles constituting the "limited reservoir") increases with increasing wind speed above the threshold velocity, estimated emissions should be related to the gusts of highest magnitude. The current meteorological variable which appropriately reflects the magnitude of wind gusts is the fastest 2-minute wind speed from the "First Order Summary of the Day," published by the U.S. Weather Service for first order meteorological stations.[8] The quantity represents the wind speed corresponding to the largest linear passage of wind movement during a 2-minute period. Two minutes is approximately the same duration as the half-life of the erosion process (i.e., the time required to remove one-half the erodible particles on the surface). It should be noted that instantaneous peak wind speeds can significantly exceed the fastest 2-minute wind speed. Because the threshold wind speed must be exceeded to trigger the possibility of substantial wind erosion, the dependence of erosion potential on wind speed cannot be represented by any simple linear function. For this reason, the use of an average wind speed to calculate an average emission rate is inappropriate.

Wind Accessibility. If the erodible material lies on an exposed area with little penetration into the surface wind layer, then the material is uniformly accessible to the wind. If this is not the case, it is necessary to divide the erodible area into subareas representing different degrees of exposure to wind. For example, the results of physical modeling show that the frontal face of an elevated materials storage pile is exposed to surface wind speeds of the same order as the approach wind speed upwind of the pile at a height matching the top of the pile;[9] on the other hand, the leeward face of the pile is exposed to much lower wind speeds.

1.4 Emission Calculation Procedure

A calculation of the estimated emission rate for a given source requires data on source extent, uncontrolled emission factor, and control efficiency. The mathematical expression for this calculation is given as follows:

$$R = SE\ e\ (1 - c) \qquad (2)$$

where:
- R = estimated mass emission rate in the specified particle size range
- SE = source extent
- e = uncontrolled emission factor in the specified particle size range (i.e., mass of uncontrolled emissions per unit of source extent)
- c = fractional efficiency of control

The source extent (activity level) is the appropriate measure of source size or the level of activity which is used to scale the uncontrolled emission factor to the particular source in question. For process sources of fugitive particulate emissions, the source extent is usually the production rate (i.e., the mass of product per unit time). Similarly, the source extent of an open dust source entailing a batch or continuous drop operation is the rate of mass throughput. For other categories of open dust sources, the source extent is related to the area of the exposed surface which is disturbed by either wind or mechanical forces. In the case of wind erosion, the source extent is simply the area of erodible surface. For emissions generated by mechanical disturbance, the source extent is also the surface area (or volume) of the material from which the emissions emanate. For vehicle travel, the disturbed surface area is the travel length times the average daily traffic (ADT) count, with each vehicle having a disturbance width equal to the width of a travel lane.

If an anthropogenic control measure (e.g., treating the surface with a chemical binder which forms an artificial crust) is applied to the source, the uncontrolled emission factor in Eq. 1-2 must be multiplied by an additional term to reflect the resulting fractional control. In broad terms, anthropogenic control measures can be considered as either continuous or periodic, as the following examples illustrate:

Continuous controls	Periodic controls
Wet suppression at conveyor transfer points	Watering or chemical treatment of unpaved roads
Enclosures/wind fences around storage piles	Sweeping of paved travel surfaces
Continuous vegetation of exposed areas	Chemical stabilization of exposed areas

The major difference between the two types of controls is related to the time dependency of performance. For continuous controls, efficiency is essentially constant with respect to time. On the other hand, the efficiency associated with periodic controls tends to decrease (decay) with time after application until the next application, at which time the cycle repeats but often with some residual effects from the previous application.

In order to quantify the performance of a specific periodic control, two measures of control efficiency are required. The first is “instantaneous” control efficiency and is defined by:

$$c(t) = \left(1 - \frac{e_c(t)}{e_u}\right) \times 100 \tag{3}$$

where:
$c(t)$ = instantaneous control efficiency (percent)
$e_c(t)$ = instantaneous emission factor for the controlled source
e_u = uncontrolled emission factor
t = time after control application

The other important measure of periodic control performance is average efficiency, defined as:

$$C(T) = \frac{1}{T}\int_0^T c(t)\,dt \tag{4}$$

where: $c(t)$ = instantaneous control efficiency at time t after application (percent)
T = time period over which the average control efficiency is referenced

The average control efficiency is needed to estimate the emission reductions due to periodic applications.

1.5 Emission Factors

Early in the USEPA field testing program to develop emission factors for fugitive dust sources, it became evident that uncontrolled emissions within a single generic source category may vary over two (or more) orders of magnitude as a result of variations in source conditions (equipment characteristics, material properties, and climatic parameters). Therefore, it would not be feasible to represent an entire generic source category in terms of a single-valued emission factor, as traditionally used by the USEPA to describe average emissions from a narrowly defined ducted source operation. In other words, it would take a large matrix of single-valued factors to adequately represent an entire generic fugitive dust source category. In order to account for emissions variability, therefore, the approach was taken that fugitive dust emission factors be constructed as mathematical equations for sources grouped by the dust generation mechanisms. The emission factor equation for each source category would contain multiplicative correction parameter terms that explain much of the variance in observed emission factor values on the basis of variances in specific source parameters. Such factors would be applicable to a wide range of source conditions, limited only by the extent of experimental verification. For example, the use of the silt content as a measure of the dust generation potential of a material acted on by the forces of wind or machinery proved to be an important step in extending the applicability of the emission factor equations to a wide variety of aggregate materials of industrial importance.

A compendium of emission factors (referred to as AP-42) is maintained on a CD-ROM (Air Chief Version 11, 2004[10]) by the U.S. Environmental Protection Agency. Chapter 13 of AP-42 contains the predictive emission factor equations for fugitive dust sources. Also with each equation is provided a set of particle size multipliers for adjusting the calculated emission factors to specific particle size fractions. The ratios of PM2.5 to PM10 published in AP-42 typically range from 0.15 to 0.25; however, recent field studies indicate that the ratios may be as low as 0.06 to 0.10. The DEJF plans to fund a series of controlled laboratory tests during 2005 to quantify the PM2.5/PM10 ratio for several resuspended soils.

Example: Vehicle Traffic on Unpaved Roads. For the purpose of estimating uncontrolled emissions, the AP-42 emission factor equation applicable to vehicle traffic on publicly accessible unpaved roads takes source characteristics into consideration:

$$E = 1.8\ (s/12)\ (S/30)^{0.5} / (M/0.5)^{0.2} - C \qquad (5)$$

where: E = PM10 emission factor (lb/VMT)
s = surface material silt content (%)
S = mean vehicle speed (mph)

M = surface material moisture content (%)
C = emission factor for 1980’s vehicle fleet exhaust, plus break/tire wear

The denominators in each of the multiplicative terms of the equation constitute normalizing default values, in case no site-specific correction parameter data are available. The default moisture content represents dry (worst-case) road conditions. Extrapolation to annual average uncontrolled emission estimates (including natural mitigation) is accomplished by assuming that emissions are occurring at the estimated rate on days without measurable precipitation and, conversely, are absent on days with measurable precipitation.

1.6 Emission Control Options

Typically, there are several options for the control of fugitive particulate emissions from any given source. This is clear from Equation 1-2 used to calculate the emission rate. Because the uncontrolled emission rate is the product of the source extent and the uncontrolled emission factor, a reduction in either of these two variables produces a proportional reduction in the uncontrolled emission rate. In the case of open sources, the reduction in the uncontrolled emission factor may be achieved by adjusted “work practices”. The degree of the reduction of the uncontrolled emission factor can be estimated from the known dependence of the factor on source conditions that are subject to alteration. For open dust sources, this information is embodied in the predictive emission factor equations for fugitive dust sources as presented in Section 13 of AP-42. The reduction of source extent and the incorporation of adjusted work practices which reduce the amount of exposed dust-producing material are preventive measures for the control of fugitive dust emissions.

Add-on controls can also be applied to reduce emissions by reducing the amount (areal extent) of dust-producing material, other than by cleanup operations. For example, the elimination of mud/dirt carryout onto paved roads at construction and demolition sites is a cost-effective preventive measure. On the other hand, mitigative measures involve the periodic removal of dust-producing material. Examples of mitigative measures include: cleanup of spillage on travel surfaces (paved and unpaved) and cleanup of material spillage at conveyor transfer points. Mitigative measures tend to be less favorable from a cost-effectiveness standpoint.

Periodically applied control techniques for open dust sources begin to decay in efficiency almost immediately after implementation. The most extreme example of this is the watering of unpaved roads, where the efficiency decays from nearly 100% to 0% in a matter of hours. On the other hand, the effects of chemical dust suppressants applied to unpaved roads may last for several months. Consequently, to describe the performance of most intermittent control techniques for open dust sources, the “time-weighted average” control efficiency must be reported along with the time period over which the value applies. For continuous control systems (e.g., wet suppression for continuous drop materials transfer), a single control efficiency is usually appropriate.

Table 1-1 lists fugitive dust control measures that have been judged to be generally cost-effective for application to metropolitan areas unable to meet PM10 standards. The most highly developed performance models available apply to application of chemical suppressants on unpaved roads. These models relate the expected instantaneous control efficiency to the application parameters (application intensity and dilution ratio) and to the number of vehicle passes (rather than time) following the application. More details on available dust control measure performance and cost are presented by Cowherd et al. (1988)[11] and Cowherd (1991)[12].

Table 1-1. Controls for Fugitive Dust Sources

Source category	Control action
Agricultural Tilling	Conservation management practices
Construction/Demolition	Paving permanent roads early in project Covering haul trucks Access apron construction and cleaning Watering of graveled travel surfaces
Materials Handling	Wet suppression
Paved Roads	Water flushing/sweeping Improvements in sanding/salting applications and materials Covering haul trucks Prevention of trackout Curb installation Shoulder stabilization
Unpaved Roads	Paving Chemical stabilization Surface improvement (e.g., gravel) Vehicle speed reduction
Wind Erosion (agricultural, open area, and storage pile)	Revegetation Limitation of off-road vehicle traffic

1.7 Document Organization

The handbook contains separate, stand-alone chapters for each fugitive dust source category with the chapters grouped into two broad categories, mechanically generated fugitive dust and wind generated fugitive dust, as follows:

- Group I. Mechanically Generated Fugitive Dust
  - Agricultural Tilling (Chapter 2)
  - Construction and Demolition (Chapter 3)
  - Materials Handling (Chapter 4)
  - Paved Roads (Chapter 5)
  - Unpaved roads (Chapter 6)
- Group II. Wind Generated Fugitive Dust
  - Agricultural Wind Erosion (Chapter 7)
  - Open Area Wind Erosion (Chapter 8)
  - Storage Pile Wind Erosion (Chapter 9)

Each chapter contains the following subsections:

- Characterization of Source Emissions
- Emissions Estimation: Primary Methodology (generally from AP-42)
- Emissions Estimation: Alternate Methodology (if available; e.g., CARB)
- Demonstrated Control Techniques
- Regulatory Formats
- Compliance Tools
- Sample Cost-Effectiveness Calculation
- References

A glossary and a series of Appendices are included in the handbook. Appendix A contains a discussion of two basic test methods used to quantify fugitive dust emission rates, namely:

- The upwind-downwind method that involves the measurement of upwind and downwind particulate concentrations, utilizing ground-based samplers under known meteorological conditions, followed by a calculation of the source strength (mass emission rate) with atmospheric dispersion equations; and
- The exposure-profiling method that involves simultaneous, multipoint measurements of particulate concentration and wind speed over the effective cross section of the plume, followed by a calculation of the net particulate mass flux through integration of the plume profiles.

Appendix B includes a summary of emission estimation methods developed by various groups for several fugitive dust source categories not addressed in the main body of the handbook. It also includes a summary of emission estimation methods for categories addressed in the handbook that are still in the "developmental" stage and have not been approved by federal or state agencies, or were developed many years ago and have fallen out of favor. The emission estimation methods discussed in Appendix B include:

- an early USEPA method for agricultural tilling,
- an early USEPA method and a California Air Resources Board (CARB) method for agricultural harvesting,
- a CARB method for cattle feedlots,
- emission estimation methods developed by AeroVironment for miscellaneous minor fugitive dust sources (leaf blowers, equestrian centers, landfills, and truck wake turbulence of unpaved shoulders),
- an early USEPA method for active storage pile wind erosion,
- an early USEPA method for uncovered haul trucks,
- a Desert Research Institute (DRI) method for unpaved shoulders, and
- four methods for open area wind erosion: the Draxler method, the UNLV method, the Great Basin Unified APCD method, and the DEJF method.

Appendix B also includes a discussion of a method developed by DRI to measure the silt content for paved roads. Because many of these methods have not been peer-reviewed, the reader is cautioned against the use of the emission factors included in these methods.

Appendix C contains a step-wise methodology to calculate the cost-effectiveness of different fugitive dust control measures. In compiling information regarding control cost-effectiveness estimates (i.e., $ per ton of PM10 reduction) of different control options for the fugitive dust handbook, we discovered that many of the estimates provided in contractor reports prepared for air quality agencies for PM10 SIPs contain either hard to substantiate assumptions or unrealistic assumptions. Depending on what assumptions are used, the control cost-effectiveness estimates can range over one to two orders of magnitude. Consequently, the end user of the handbook would get a distorted view if we published these estimates. Rather than presenting these published cost-effectiveness estimates, we have prepared a detailed methodology containing the steps to calculate cost-effectiveness that is included in Appendix C. We recommend that the handbook user calculate the cost-effectiveness values for different fugitive dust control options based on current cost data and assumptions that are applicable for their particular situation.

1.8 References

1. Cowherd, C. Jr., Axetell, K. Jr., Maxwell, C.M., Jutze, G.A., 1974. *Development of Emission Factors for Fugitive Dust Sources*, EPA Publication No. EPA-450/3-74/037, NTIS Publication No. PB-238 262.

2. ASTM, 1984. American Society of Testing and Materials, Subcommittee C09.03.05. Standard Method for Sieve Analysis of Fine and Coarse Aggregates, Method C-136, 84a, Philadelphia, PA.

3. Cowherd, C. Jr., Bohn, R., Cuscino, T. Jr., 1979. *Iron and Steel Plant Open Source Fugitive Emission Evaluation,* EPA-600/2-79/1 03, NTIS Publication No. PB-299 385.

4. Woodruff, N.P. Siddoway, F.H., 1965. *A Wind Erosion Equation*, Soil Sci. Soc. Am. Proc. 29(5):602-8.

5. Cowherd, C. Jr., Muleski, G.E., Englehart, P.J., Gillette, D.A., 1985. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites,* EPA/600/8-85/002; report prepared for USEPA.

6. Gillette, D.A., 1978. *A Wind Tunnel Simulation of the Erosion of the Soil,* Atmos. Environ., 12: 1735-43.

7. Cowherd, C. Jr., 1988. A Refined Scheme for Calculation of Wind Generated PM Emissions from Storage Piles, in *Proceedings: APCA/EPA Conference on PM10: Implementation of Standards;* report prepared for USEPA.

8. NEDS, 1992. Local Climatological Data: Annual and Monthly Summaries, National Environmental Data Service, National Climatic Center, Asheville, NC.

9. Billings-Stunder, B.J. and Arya, S.P.S., 1988. *Windbreak Effectiveness for Storage Pile Fugitive Dust Control: A Wind Tunnel Study*, J. Air Pollution Control Assoc. 38: 135-43.

10. Air CHIEF CD-ROM, Version 11, U.S. EPA, 2004. Research Triangle Park, NC.

11. Cowherd, C. Jr., Muleski, G.E., Kinsey, J.S., 1988. *Control of Open Fugitive Dust Sources*, EPA 450/3-88-008; report prepared for USEPA.

12. Cowherd, C. Jr., 1991. *Best Available Control Measures (BA CM) for Fugitive Dust Sources.* Revised Draft Guidance Document; report prepared for USEPA.